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Hard protection structures as a principal coastal erosion management strategy along the Caribbean coast of Colombia. A chronicle of pitfalls

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ABSTRACT

Over the last 50 years, coastal erosion has become a serious problem, rising in magnitude and dominance along the Caribbean coastline of Colombia. *Circa* 50% of this important area for the country is undergoing serious erosion problems related to a multiplicity of factors contrasted by their degree of influence and magnitude, e.g. sedimentary imbalances, extreme waves, ecosystems destruction and sea level rise. Coastal protection related with hard structures has been the first, and in some cases, the only management strategy for these erosion problems. At the beginning of 2016, at least 1484 hard structures (both cross and longshore, such as, groins, seawalls, breakwaters, amongst others) have been built along the Colombian Caribbean coast, the highest concentrations being found in tourist cities. A significant percentage (close to 90%) of these hard structures have not been very successful or have failed in their purpose. These hard structures have altered the natural conditions of the study area, producing impacts such as i) coastal armoring, ii) reduced sediment supplies to downdrift areas, iii) intensification of erosion processes, iv) generation of nearby new erosion hot spots, v) deterioration of coastal scenery quality, among others. This paper describes and evaluates the functionality of coastal protection strategies used up to the present and delves into management aspects of coastal protection in the Caribbean coast of Colombia. It also indicates the current and future coastal protection scene for the region and highlights major trends and challenges faced by users, land owners, and coastal managers.
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1. Introduction

Coastal communities around the world face serious problems related to coastal erosion (Pilkey and Cooper, 2014). This process is magnified by the existing conditions of a warming climate that have resulted in constant inundation and an increased risk of flooding during extreme wave events (Donnelly et al., 2004; Aerts et al., 2014; Jin et al., 2015). Coastal erosion issues become more critical because coastal zones are optimal places for population concentration and the development of productive activities, such as, industry, transportation, tourism, etc. (Barragan and Andreis, 2015).

Adger et al. (2005) indicated that close to 20% of the world population (1409 million inhabitants) reside less than 25 km from the coastline, and 40% (2818 million inhabitants) live less than 100 km inside a coastal strip representing approximately 25% of the world total surface. From 1950 to the present, coastlines of the world have experienced rapid development with an annual average urban growth of 2.6% (UN-Habitat, 2009). For the same period the number of coastal cities has multiplied by 4.5 times going from 472 in 1950 to 2129 in 2015. It has been estimated that almost 30% of residences within 200 m along low coasts, may be severely affected by erosion-related property losses over the next 50 years (UN-Habitat, 2009).

One of the prerequisites for sustainable coastal development, on a national, regional or local scale, is adequate zoning and implementation of optimal coastal erosion management strategies (EU, 2004; Boruff et al., 2005; Pranzini and Williams, 2013; Rangel-

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Buitrago and Anfuso, 2015). The different strategies have become an issue of widespread worldwide concern. Unfortunately, most coastal erosion management decisions are conditioned by economic considerations manifested on an action-reaction basis (Rangel-Buitrago et al., 2015a,b) or a cost-benefit analysis approach (Cooper and McKenna, 2007).

Management strategies must include techniques, knowledge, equipment, and institutional instruments designed to minimize or eliminate coastal erosion related impacts. These must have an optimal benefit to reducing society's vulnerability due to coastal erosion hazards. Considering actual, and future climate change scenarios, management strategies must also allow coastal communities to minimize their detrimental impacts while benefitting from any potential positive consequences.

The typology of coastal management strategies approaches was first suggested by IPCC CZMS (1990) and includes four generic options:

- **Protect**: preserve vulnerable areas, especially population centers, economic activities and natural resources using hard structures and/or soft protection measures.
- **Accommodate**: persist in occupying sensitive areas, but accept a greater degree of flooding by changing land use, construction methods and improving preparedness.
- **Planned retreat**: remove structures in currently developed areas, resettle inhabitants and require that new development is set back from the coast, as appropriate.
- **Do nothing: (no actions planned)**.

It is important to note that coastal erosion management consists of more than just implementing one of the four interventions options. Coastal erosion management is a policy and implementation process involving general decision-making and technology application (Zhu, 2010) and the most successful management is integrated within the activities of all planning departments, rather than acted upon in an isolationist way (Tompkins, 2005).

Coastal erosion is a common problem affecting about 75% of the world's shorelines (Bird, 1985; Zhang et al., 2004; Pilkey and Cooper, 2014). This process has changed the Colombian Caribbean coast during the last 50 years bringing significant ecological impacts, high economic losses and socio-political problems (Rangel-Buitrago et al., 2015a,b). At least 50% (1182 km) of the Colombian Caribbean coast is facing severe coastal erosion (more than 1.5 m yr^{-1}), 32% (812.6 km) can be considered as stable, and only 18% (450.5 km) is accreting. Currently, coastal erosion produces not only beach loss but also a deterioration of scenic quality, that is becoming a problem that hinders economic growth of the country.

Recent history suggests that developed coastal management strategies for Colombia are designed to control and mitigate coastal erosion. This is achieved by protection based upon the construction of hard defense structures, a process known as coastline armoring (Griggs, 2005; Charlier et al., 2005). This is founded principally on an action-reaction, or post-disaster basis, entailing that initiatives are usually triggered by emergencies, not by prevention.

Over the last decade, the expanded level of coastal armouring and its negative influence has been seen as a critical problem along this coastline. Management strategies have involved traditional onshore structures that generate some adverse effects, such as:

- Accelerated bottom erosion in front of the hardstructures and downdrift scouring.
- Disturbance of sediment supply and beach reduction.
- Restricted public access.
- Potential risks for bathers.
- Aesthetic visual effects on the seaside landscape.

There are many examples where millions of dollars of public investment were urgently approved to mitigate erosion (Rodriguez-Ramírez et al., 2008; Botero et al., 2013a,b; Flor-Blanco et al., 2015; Rangel-Buitrago et al., 2015a). In most cases, these "coastal erosion solutions" were poorly designed and hurriedly constructed in order to reduce the erosion process impact generating an "express" coastal defense structure that was not fit for purpose. Despite the adverse effects, implementation of hard structures as protection measures against coastal erosion prevails. The above demands correct application of adequate management policies to preserve ecosystems as well as socio-economic activities.

This paper assesses the coastal erosion management strategies used along the Caribbean coast of Colombia by analysing the distribution, characteristics, and effects of hard protection structures, which seemingly are the only management strategy for erosion problems along the Caribbean coast.

Attempts to illustrate the role of national politicies and priorities represents a choice of existing and future coastal stabilization techniques. Results presented in this work are useful to local and national coastal managers and planners, who need coastal inventories based on ascertained facts in order to adopt sound management decisions.

1.1. The Caribbean coast of Colombia: regional setting

The Colombian Caribbean coast extends for 2445 km, between the E boundary with Venezuela and the W boundary with Panama (Fig. 1). Its general, orientation is NE – SW with some sectors oriented W-E so that long linear segments alternate with bays. This coastline is a complex region where tectonic processes have defined the actual topography with landscape units that include medium - high relief mountain areas and low relief deltaic plains (Correa and Morton, 2011; Rangel-Buitrago et al., 2013).

Quaternary interactions among tropical climate, oceanographic processes, and tectonic activity make a varied unstable littoral geomorphology characterized by beaches along the flat coastal plains, spits, and cliffed coastlines (commonly terraced) along the coastal rock areas (Martínez et al., 2010).

Seasonal precipitation shows two rain periods, i.e. April–May and October–November and two dry periods, i.e. November–April and July–September. Maximum annual precipitation values are *circa* 2500 mm, while mean monthly temperatures of <28° C, makes coastal environments attractive for tourism development (Rangel-Buitrago et al., 2013).

Tides are mixed semi-diurnal, with maximum amplitudes of 65 cm (Andrade, 2008). Average significant wave height fluctuates between 1 and 2 m and peak period average values vary between 6 and 10 s. From November to July, the wave system is dominated by NE swells; for the remainder of the time, waves from NW, WSW and even SW occur. This wave direction seasonal variation corresponds with a decrease in significant wave height, with the lowest values occurring between August and October ($\leq$1.5 m); whereas highest energy conditions occur from November to July where wave heights can exceed 2 m (Restrepo et al., 2012).

Longshore sand drift has a dominant south-westward component, but minor reversals to the northeast occurs during rain periods when southerly winds become dominant in some sectors and set up short, high-frequency waves able to cause significant shore erosion along cliffed and mud coastlines (Correa and Morton, 2011).

2. Methodology

Mapping or indicating human modifications of the coast (coast-protection structures) is a vital element of identifying areas most

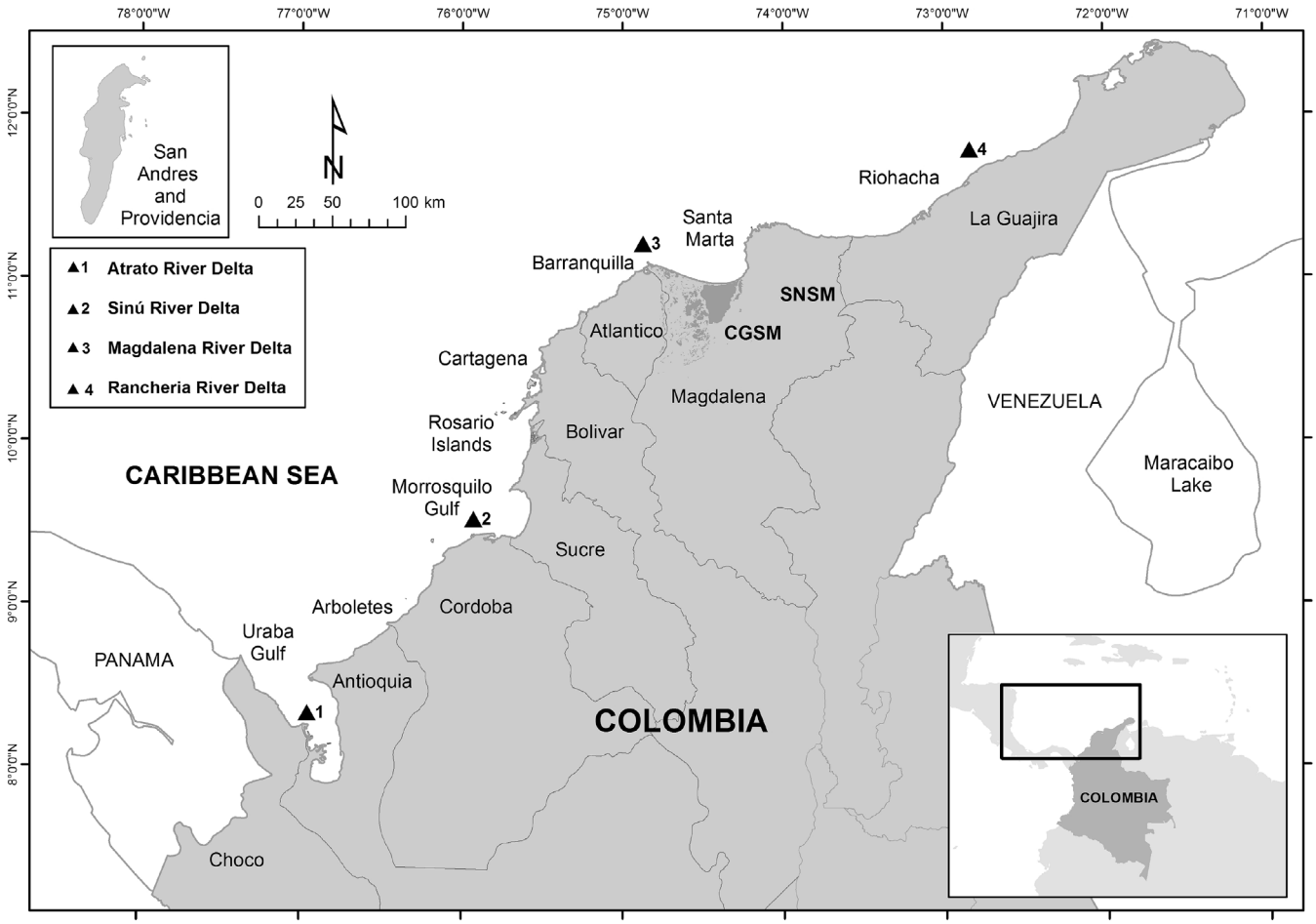

Fig. 1. Study area with indication of principal river deltas.

sensitive to various coastal risks. Such indicative typology or segmentation would help highlight the state of the coastline and form the first base line for vulnerability assessment useful in any coastal decision-making (Anfuso and Martinez del Pozo, 2005; Rangel-Buitrago and Anfuso, 2015).

The analysis of the protection given by hard structures was assessed over the 2000–2016 period (Table 1) by satellite images of different scales.

A critical issue is selection of an adequate feature that can serve as a shoreline indicator that correctly reflects real shoreline position (Boak and Turner, 2005). For differentiation and later digitizing, the infrared band on each available image (i.e. fourth band of the Landsat image) was selected. In this micro-tidal environment, this shoreline indicator is defined as the water line when the image was taken (Boak and Turner, 2005). Because it was not possible to reconstruct tidal conditions at the moment the image was taken, it was assumed that the daily water line position is subject to a maximum uncertainty of 7 m, taking into account the average intertidal slope of Colombian Caribbean beaches (Rangel-Buitrago and Anfuso, 2009). Wave height effects were not considered because no storm conditions were observed in any of the images used.

After shoreline position identification, images were digitized on a GIS environment (ARCGIS 9.3) for subsequent analysis. In order to obtain the number of structures with their respective spatial location and characteristics, all hard protection structures were counted within a zone extending from the shoreline to a landward distance of 100 m. Information obtained was revised and complemented by accurate field observations regarding the key features, composition, and usefulness of coastal protection structures with the goal to obtain a final number of structures in each location. The number of coastal protection structures observed along the study area were grouped into five categories (Absent, Experiment, Infrequent, Moderately present, Frequent) according the classification proposed in Pranzini and Williams (2013) and Pranzini et al. (2015).

Table 1
Satellite images used in this work.

Satellite images			
Source	Year	Resolution (m)	Coverage
Glovis Nasa Landsat	2000 to 2016	30	Entire Caribbean coast of Colombia
Terraserver Geoglove	2000 to 2016	0.5	Riohacha, Tasajera (Km 18–21), Tolu and Coveñas, Corales del Rosario and San Bernardo, Cartagena

The most critical areas with a developed coastal protection were selected for evolution analysis, evaluation of the usefulness of the structure and determination of their related impacts.

3. Results and discussion

3.1. Coastal settlements along the Caribbean coast of Colombia

As observed worldwide, coastal urbanization and armoring processes have been strictly associated with an increase in coastal population and tourism related activities (Pilkey and Cooper, 2014; Barragan and Andreis, 2015; Manno et al., 2016).

The main Colombian coastal occupation started with the Spanish colonization during the 16th century, through construction of coastal towns and settlements particularly those related to maritime transport. Exportation of goods, such as, coffee, sugar, essentially took place through shipping, which facilitated construction of harbours and ports, as well as defense structures to avoid pirate related attacks (Rangel-Buitrago et al., 2011).

Over the past century, Colombia's Caribbean coastline has experienced a trend of increasing population compared to inland areas due mainly to the economic opportunities that exist. This process has also been favoured by migration of citizens to larger coastal towns after public order problems during the early 1970s. Since then the coast has become highly developed and urbanized, e.g. during the 1970–2016 period the number of residents of Cartagena city increased from 348,961 to 1,001,680 inhabitants, an incremental rise of 187%.

The investigated area consists of 28 municipalities (smallest administrative territorial units) that shape eight departments with 4,175,876 inhabitants. This population (8.5% of the total national), is mainly concentrated in four commercial and tourist cities: Barranquilla, Cartagena, Santa Marta and Riohacha (DANE, 2016).

"Sun, Sea, and Sand" tourism represents one of the most important activities, with 2,441,033 international arrivals per year and 4,000,000 domestic tourism arrivals in the study area during the last seven years (ANATO, 2016). An increase of 30,000 international arrivals occurred between 2013 and 2015, and the same behaviour was recorded with 165,200 foreign visitors during January–March, 2016 (ANATO, 2016). The tourist industries rapid growth has generated an increase of almost US$ 300 million per year in the Colombian Gross Domestic product (BANREP, 2015) and, tourism represents > US$ 3600 million in the balance of payments for travel/transportation, It is the third highest source of foreign exchange after oil and coal (ANATO, 2015; Williams et al., 2016a).

Unfortunately, tourism development has posed some threats to the Colombian Caribbean coast. Over the last 30 years, while tourism activities increased, coastal erosion became a serious problem rising in magnitude and dominance (Rangel-Buitrago et al., 2015a,b). There has been a significant residential growth along the shoreline; also recent tourist arrivals have dramatically increased the total number of coastal inhabitants during holidays. Cartagena, Santa Marta, and San Andres are the most visited destination for "Sun, Sea and Sand" experiencing a considerable increase of tourism developments principally consisting of five-star hotel chains and golf courses. Further developments are observed in the remaining coastal cities consisting of enlargement of existing coastal towns and villages with associated impacts on coastal scenery (Rangel-Buitrago et al., 2013; Williams et al., 2016b).

High pressure to build hotels and summer houses for local and foreign tourists has resulted in a significant increase in the construction of buildings along the study area, even on National Natural Parks. This increase has led to a significant demand for coastal space and sand, as well as increased activity in protected areas with the existing coastal erosion problems.

Additionally, coastal population growth has had a significant impact on the coastal geomorphology, since higher population concentrations have necessitated a larger number of hard protection measures to mitigate coastal hazards. In some municipalities, current facilities are not able to cope with the additional population and this has adversely affected marine ecosystems, such as, corals, seagrasses, and mangroves. Likewise, the increased coastal infrastructure required by the new population is also affected by acceleration of coastal erosion processes (Stanchev et al., 2015).

3.2. The coastal erosion problem (magnitudes and causes)

A recent analysis of coastal evolution trends by Rangel-Buitrago et al. (2015a,b) for this area revealed that 49% of this coastline is undergoing severe erosion problems (Table 2). Spatial and temporal variability of this process can be related to coastal heterogeneity alongside a diversity of factors that contribute to erosional behaviour with different influences. Also, the increasing erosion rates suggests an importance of both natural and human-induced processes. Sedimentary imbalance perhaps is the primary factor contributing to high erosion rates found, which are related to dams (Correa and Vernette, 2004; Rangel-Buitrago and Posada, 2005), sand mining (Correa and Alcántara, 2005; Rangel-Buitrago et al., 2015a,b; Vallejo et al., 2016), ecosystem destruction (Botero and Salzwedel, 1999; Vilardy et al., 2011) and emplacement of coastal engineering structures (Rangel-Buitrago et al., 2011, 2015a,b; Stancheva et al., 2011).

The high erosion rates observed on this coast suggest that sediment supply (terrigenous and calcareous) is much less than the littoral transport capacity (Correa and Alcántara, 2005; Rangel-Buitrago et al., 2015a,b). Sediment supplies derived from eroding cliffs, sand beaches and dunes being insufficient to balance the sediment budget deficit. The morphology of the principal river deltas has been subject to substantial change, due to multiple river basin interventions. For example, dam construction favoured accumulation of coarser sediments in artificial lakes and only fine-grained sediments arrived at the coast. This fine suspended sediment has contributed to the partial disappearance of coral and algae ecosystems and to a considerable reduction in abundance of sea grass beds, confirmed by Gardner et al. (2003) and Restrepo et al. (2012) who associated coastal ecosystems destruction to river derived fluvial fluxes.

For the Caribbean coast of Colombia there are only data the last 60 years as collected by the Global Sea Level Observing System (http://www.psmsl.org/data/obtaining/stations/572.php). These data suggest a relative sea level rise (RSLR) increment of 5.5 mm yr^{-1}. This fits the global trend estimated by the IPCC (2013) inferring an approximate elevation of 0.50 m in the next 100 years. We know that there is also subsidence along the coast but we have sofar no data to support its importance. The process of land subsidence still needs be studied along the study area. Despite the data limitations, is necesarry indicate that during this period of apparently rapid SLR as suggested by IPCC there has not have been enough time for constructive forces to reach equilibrium along the beaches and much sand delivered by rivers has been left in-situ. The most dramatic effects of these apparent SLR changes occur at Cartagena city, Santa Marta and islands (i.e., Rosario, San Bernardo and San Andres), where extreme high tides produces severe inundations.

Hurricanes and cold fronts also play a major role in the coastal erosion magnitudes observed along the study area. Hurricanes often originate in the Caribbean from June to November and affect coasts with high winds, heavy rains, and storm waves. Cold fronts have their origins during January, February and March and cause strong swell waves whose impact may be increased by trade winds

Table 2
Coastal evolution trend categories along the Caribbean coast of Colombia (Rangel-Buitrago et al., 2015a,b).

Department		Type				
		High Erosion	Erosion	Stability	Accumulation	TOTAL
La Guajira	Length (km)	153.0	154.9	348.1	41.1	**697**
	Percentage (%)	22	22	50	6	
Magdalena		52.1	186.9	24.1	38.9	**302**
		17	62	8	13	
Atlántico		18.4	18.3	16.5	17.8	**71**
		26	26	23	25	
Bolívar		111.0	83.0	228.1	46.9	**469**
		24	18	49	10	
Sucre		26.5	19.8	54.5	11.2	**112**
		24	18	49	10	
Córdoba		52.8	70.6	36.2	69.4	**229**
		23	31	16	30	
Antioquia		76.5	128.4	60.4	223.8	**489**
		16	26	12	46	
San Andres and Providencia		11.3	18.6	44.9	1.3	**76**
		15	24	59	2	
TOTAL	**Length (km)**	**502**	**680**	**813**	**450**	**2445**
	Percentage (%)	**21**	**28**	**33**	**18**	**100**

blowing from ENE, often striking the coast 48 h later with a common occurrence of six events per year (Ortiz et al., 2013). These high-energy events generate serious damage and an extended recovery period is necessary before beaches can return to equilibrium (Rangel-Buitrago and Anfuso, 2011), as the system requires greater sediment volumes and longer time periods for system recovery (Lentz and Hapke, 2011).

3.3. The Colombian strategy: hard structures as a management tool

Along the Caribbean coastline of Colombia, control over coastal erosion processes have been implemented *via* traditional hard defense options (Tables 3 and 4). During the last 30 years, the necessity to protect the coast with hard structures has been driven by the growing coastal zone population and political - economic pressures. At the beginning of 2016, at least 1484 both cross and hard longshore structures have been built along the coastline, with the highest concentrations being located in Cordoba, Sucre, and Bolivar Departments and the cities of Cartagena and Santa Marta (Table 4).

In general terms, hard structures are very similar over the study area, both in available material type (generally calcareous rocks) and concept. Colombian protection measures were made under the Spanish - Italian coastal protection concept – a hard approach, but over the last two years, unsuccessful attempts have been made to explore the Dutch concept of Building with Nature, *i.e.* a softer approach.

The following lines focus on the most commonly deployed protection structures, including groins, breakwaters, and seawalls. In some cases, structures are hybrids that tend to incorporate functions of more than one traditional design without optimal results. Some "experimental" structures exist (e.g. wave attenuators and beach dewatering), but they are deployed in limited numbers, are often temporary and have shortcomings similar to traditional approaches (Cooper and Pilkey, 2012; Nordsrom, 2014; Williams et al., 2016b). Due to the scale of this work, some effects of traditional structures are still unknown, and many issues remain to be solved.

3.4. Groins: the people's favorite choice

Groins are the most common engineering practice for protecting the coast against erosion along the study area (Fig. 2). This protection measure is also the oldest used coastal protection structure in Colombia and until now still represents the most important, sometimes the only, Colombian strategy towards coastal erosion management. Groins can be found along the entire study area in significant numbers (905 units), specially in tourist cities, such as, Santa Marta, Cartagena, and Riohacha where more than 200 groins exist (Fig. 2). These structures are deployed as entire systems to influence shoreline sediment transport as a result of longshore currents. They are mostly constructed as porous structures consisting of blocks of calcareous rocks obtained from Tertiary rocks extracted from nearby quarries. Others have been made from concrete tetrapods, concrete rests, geotextile bags, corals, tires and even significant amounts of litter (Fig. 2).

A negative impact of groins on downdrift areas is well observed in almost 85% of cases along the study area. Sediment moving along the coast in the downdrift direction is trapped on the updrift side of the structure, generating a sand deficit and increasing erosion rates on the downdrift side (Bush et al., 1996).

"Empirical" construction of groins is a common practice within the area. A significant percentage of the people have no knowledge of the function of this structure and its negative impact when constructed with limited design information. In many instances, people with no knowledge regarding the causes of erosion, try to resolve the problem intuitively. Usually, coastal inhabitants collect stones from nearby quarries, produce low-cost concrete blocks, use concrete remains, tires and in some cases litter to build a groin to stop the perceived erosion. This practice is a problem because it has generated armored coastlines in remote areas, such as, the Antioquia, Cordoba, and Sucre Departments. In some cases, tires and litter used as groins have been moved during storm events generating damage to animals and humans. For example, along the Palomino coastline (La Guajira Department), the turtles nesting season has been compromised several times due to the movement of tires, which have been used as groins. The "empirical" construction is a common practice and due to high erosion rates are usually used as the first "solution" to control erosion and protect property.

3.5. Seawalls, revetments, and rip-raps: 'our' problem, 'my' individual solution

Seawalls, revetments, and rip-raps are another common protection method applied on the Colombian Caribbean coast. Designed structures are mostly vertical and smooth, which

Table 3
Current coastal protection structures present along the study area (1: Absent, 2: Experiment, 3: Infrequent, 4: Moderately present, 5: Frequent).

STRUCTURE		DEPARTAMENT							
		GUAJIRA	MAGDALENA	ATLANTICO	BOLIVAR	SUCRE	CORDOBA	ANTIOQUIA	SAN ANDRES
Seawall	Concrete	4	4	4	5	5	4	4	4
	Bricks	2	2	2	2	2	2	2	2
	Stones	4	4	4	4	4	4	4	4
	Wood	1	1	1	1	1	1	1	1
	Fibreglass	1	1	1	1	1	1	1	1
	Gabions	1	2	2	2	2	1	1	1
Revetment (interlocking blocks)	Natural Stones	3	3	3	3	3	3	3	3
	Concrete s/bags	3	3	3	3	3	3	3	3
	Gabions	1	1	1	1	1	1	1	1
Rubble mound or Rip-Rap		4	4	4	4	4	4	3	3
Surfing reefs		4	1	1	1	4	1	1	4
Detached Breakwaters	Rocks	3	4	1	5	5	4	4	1
	Concrete	1	1	1	1	1	1	1	1
Groins	Emerged	5	5	5	5	5	5	5	5
	Submeged	5	5	5	5	5	5	5	5
	Mixed	5	5	5	5	5	5	5	5
	Permeable	2	1	2	3	3	3	2	2
Beach Nourishment	Sand	1	3	1	3	2	2	2	2
	Gravel	1	1	1	1	1	1	1	1
Dunes	Reconstruction	1	1	1	1	1	1	1	1
	Stabilization	2	1	2	1	1	1	1	1
	Construction	1	1	1	1	1	1	2	2
Posidonial and or mangroves	Natural	1	2	2	1	2	1	1	1
	Artifical	1	2	2	1	2	1	1	1
Cliff Stabilization		1	1	2	1	1	2	2	1
Tyres		3	3	2	2	1	2	2	2
Jetties		1	2	2	2	2	2	2	2

promotes scouring of the structure's foundation or toe and leads to their further destruction.

The first seawalls, revetments, and rip-raps were built during Spanish colonial times, principally along the coasts of Cartagena and Santa Marta cities. Protection of property was the principal goal of these structures that are being built at present mainly to prevent collapse of houses or buildings located on the coast and to stop destruction of threatened coastal roads.

When erosion is extreme and threatens expensive houses or the national interest structures (i.e. main roads), strong concrete seawalls are used; or different measures are combined to produce the "best" protection scheme. Such examples can be found in Km 18–21 (Magdalena) and Tierrabomba (Bolivar) more often than not, the structures are additionally reinforced with groins (Fig. 3).

Vertical seawalls and revetments usually accompany and protect coastal roads (e.g. Cartagena) causing the loss of kilometers of valuable beach, producing a strong visual effect on the landscape and tourist industry (Fig. 3). In some cases, particularly when the beach zone is narrow, rock armouring is used to protect the seawall or revetment toe against undermining (Fig. 3). At present, the most common 'hard' defense currently employed to protect private property or infrastructure of low importance and economic value, consists of designed walls and revetments constructed of boulders of a rather uniform size (25–65 cm).

Wave reflection on these structures generates or increases beach erosion and steepening the profile, inducing an irreversible process as waves moving in deeper waters lose less energy. Seawalls, revetments, and rip-raps are never built simply to protect the

Table 4
Shore protection structures within the Caribbean coast of Colombia.

Department	Groin		Breakwater		Seawall, Revetments, Rip-Raps		Other		Total	
	N	Length (m)	N	Length (m)	N	Length (m)	N	Length (m)	N	Length (m)
LA GUAJIRA	55	1689	8	456	18	426	33	636	**114**	**3207**
MAGDALENA	56	1265	23	1005	17	942	29	5214	**125**	**8426**
ATLANTICO	31	2123	0	0	12	523	19	7596	**62**	**10242**
BOLIVAR	185	5364	32	2365	62	13523	42	28399	**321**	**49651**
SUCRE	254	9426	32	901	23	1356	15	586	**324**	**12269**
CORDOBA	135	3845	25	920	52	1562	28	462	**240**	**6789**
ANTIOQUIA	156	4961	23	5785	23	486	21	447	**223**	**11679**
SAN ANDRES	33	521	0	0	24	469	18	456	**75**	**1446**
TOTAL	**905**	**29194**	**143**	**11432**	**231**	**19287**	**205**	**43796**	**1484**	**103709**

Fig. 2. Groin examples along the study area. a) Tire groin at Palomino (La Guajira), b) Geotextile bag groin at Playa Salguero (Magdalena), c) L groin at Salgar (Atlantico), d) Groin field at Lagito beach (Cartagena, Bolivar), e) Groins made with Calcareous rock at Tolu (Sucre), f) Calcareous rocks and heavy-large litter as groin at Tierrabomba (Bolivar), g) Pentapods Groin in a National Natural Park (CRSB).

beach. Rather, they are built to protect property, structures or a cliff from erosion in what can be considered an individual protection scheme. Construction of these protection structures becomes a financial issue. The premise "if you can pay it, you can get it" explains the boom in the building of such structures along the study area. Most coastal land owners and stakeholders usually spend substantial amounts of money in building these structures when they believe there is an erosion hazard (similar to groin construction). Usually, wealthy people use expensive materials, such as, blocks of plutonic rocks, while, poorer people use significant amounts of heavy litter (e.g. plastics, metal and processed wood). Irrespective of the amount of money invested, invariably these structures are not carefully built due to the urgency of stopping the coastal erosion process. In some cases they are packed too densely, acting as a concrete wall and the fronting beach either becomes narrower or disappears. In other situations, the number and weight of stones are not adequate, being rapidly destroyed by extreme events contributing to anacceleration of erosion as a consequence of scouring when water overtops the structure.

3.6. Detached breakwaters: 'trying to generate beach'

Breakwaters are the third most common engineering practice for protecting the studied area's coast. There are at least 143 breakwaters placed parallel, and in some cases oblique to the shoreline, to reduce or eliminate wave energy and contribute to deposition on beaches landward of them. Cost limits their construction to tourist areas, as well as , Cartagena and Tolu - Coveñas sector, their principal goal being regeneration of salients and tombolos for beach zone generation, as well the building of small boat harbours.

The first known breakwater was the Spanish defense called "La Escollera de la Marina" constructed in Cartagena de Indias during 1771, which served as protection from English pirates specially the Welsh pirate Henry Morgan.. Use and diffusion of breakwaters is more recent, specifically from the 80s with the sun and beach tourism boom and these structures have become increasingly popular during the last decade. In a few cases, they have replaced existing groins systems, as in the coastal zone of Tolu - Coveñas (Sucre).

The most common technique used for breakwater construction consists of sinking casts, sometimes small boats, filled with calcareous rocks extracted from nearby quarries (Fig. 4). Some of the small breakwaters (e.g. Tolu and Coveñas, Sucre) were constructed in an empirical way, based on the consultant's local experience.

The breakwater elements are nearly homogeneous with no core or filter layer. The weight of the calcareous rocks, used in

Fig. 3. Seawalls, revetments, and rip-raps examples along the study area. a) Seawall protecting a salt harvest pool at Manaure (La Guajira), b) revetment at Km 19 (Magdalena), c) revertment at Salgar (Atlantico), d) Revertement protecting historic wall at Cartagena de Indias (Bolivar), e) Revertment protecting summer house at Coveñas (Sucre), f) Geotextile bag revertment at San Andres Island, g) Gabion seawall at CRSB.

construction, ranges between 0.5 and 4 tons. The heaviest rocks are used for the armour layer and crown where the greatest wave energy is concentrated. Typical examples of the Colombian Caribbean breakwaters are presented in Fig. 4.

Breakwaters are used in systems with normally up to six elements, but in Coveñas (Sucre Department) up to twelve breakwater elements have been built consecutively, with lengths varying between 60 m and 300 m. The distance of the detached breakwaters from the shore is between 100 m and 150 m, with crests ranging from 0 m to 2.5 m above mean sea level. In breakwater system, such as, Coveñas and Cartagena, the average gap between the breakwater elements ranges from 40 m to 70 m.

Along the study area, a decrease in water quality, downdrift erosion and increased rip currents in gaps have been experienced and in some cases, deaths by drowning have occurred, due to rip currents generated, as well as, currents exiting through existing gaps (e.g. Marbella, Cartagena). For new projects, a submerged segment at approximately 0.5 m–1.5 m below mean sea level is being constructed to fill the generated gaps (e.g. Tierrabomba, Bolivar).

From a functional standpoint the Colombian engineering community has considered breakwaters as difficult structures to design. So breakwaters are much less commonly used than groins in the Colombian Caribbean coast for beach protection, due to their lower functionality and much more expensive implementation costs. However, for stakeholders, decision makers and especially politicians, breakwaters are always the first option in “coastal erosion management plans” because their high construction costs are a perfect scenario for significant amounts of money!

3.7. Selected case studies

Along the Caribbean of Colombia, there are many examples of pitfalls related to the construction of hard structures as a management strategy against coastal erosion. The most significative examples are given below.

3.7.1. The solution is not complete: groins at Riohacha (La Guajira)

Riohacha City with a total population of 259,509 inhabitants is located in northeast Colombia and the shoreline includes the Rancheria River deltaic system, coastal lagoons, and beaches. During the last 40 years, the beach of this city has registered erosion rates ranging from 1.5 to 4 m yr^{-1} (Rangel-Buitrago and Anfuso, 2009, 2015; Botero et al., 2013a,b). A “coastal erosion plan” with the purpose of controlling the erosion process and generating new beaches was designed. It contemplated the construction, along the entire municipality coastline, of twelve groins and one seawall.

During 2006 the local government approved just a part of the project based on the premise of recovering first, the tourist area due to its economic importance. At the end of 2007 six groins were

Fig. 4. Detached Breakwater examples along the study area. a-d) detached breakwaters at Cartagena de Indias (Bolivar) – oblique photos and Terraserver image for 2014, e-f) Detached breakwaters at Tolu-Coveñas Sector (Sucre) - oblique photos and Terraserver image for 2015.

constructed, 150 m length, 13 m wide and 6 m in height with an average separation of 250 m along the 1.5 km of the Riohacha City promenade (Fig. 5). Construction of these structures required approx 70,200 m^3 of calcareous sandstone blocks and had a total cost of US $7.5 millions. These hard structures allowed an extreme accumulation of sand, generating beaches 200 m wide and "partially solving" the problem along the tourist area.

However, along the southernmost area, groin construction generated erosion rates up to 5 m yr^{-1} and impacted four neighbourhoods that held at least 20% of the total city population (Fig. 5). At present, evacuation of these neighborhoods is imminent raising severe socio-economic problems to the municipality. Riohacha Municipality plans construction of at least six more groins (the rest of the intended solution) at a cost of US $2.5 million to solve the erosion problem.

These hard structures themselves will not be useful unless they are complemented with a Sand Bypass System. This system will allow the use of excess of sand accumulated at the northern part to mitigate coastal erosion effects in the southward part of the Riohacha Municipality.

3.7.2. Road problems: failed breakwaters - groins and the current revetment along the 18–21 km of the road between Barranquilla and Santa Marta cities

One of the most famous coastal erosion hotspots is the named "18–21 km sector", on the main road between Barranquilla and Santa Marta (Fig. 6). This 3 km sector, has experienced significant changes in the last twenty years with erosion rates that reached 21 m yr^{-1} (Rangel-Buitrago et al., 2015a,b). Coastal erosion is mainly related to a human-induced sedimentary imbalance that affects two significant ecosystems: the barrier islands system of the Cienaga Grande de Santa Marta and Pajarales Lagoon Complex (Rangel-Buitrago et al., 2015a,b; Gomez et al., 2016).

During 2010, in a first attempt to control the erosion process, three breakwaters were designed 125 m from the coastline, each one separated by 300 m (dimensions: 120 length, 10 m width and 2.5 m high). These breakwaters would be complemented by three perpendicular groins of 125 m length, 10 m with and 2.5 m high; both constructed with calcareous rock blocks, which ranged 0.5–1.5 tons (Fig. 6).

In 2011 construction began of the previously mentioned structures with an initial investment of US $7 million and a large amount of associated technical, economic and political pressure. The final breakwater position changed several times producing a structure completely different than the originally planned (breakwaters were constructed with lighter rocks, and also 40 m far from the coastline, not 125 m as originally planned). During a series of storm events in January 2014 extreme coastal erosion and the destruction of the recently constructed breakwaters occurred, leaving the coastal road just 3 m from total collapse (Fig. 6).

Fig. 5. Riohacha Guajira study case. a-b) groins building along city promenade. c-d) erosion related damages after groin construction (oblique photos, Satellite and Terraserver images for 2006–2016 period).

As a first protection measure after the emergency, a series of concrete bags were positioned along 350 m of coast road to avoid destruction of the road. At the same time, local and national authorities enacted a manifest urgency law that allowed fast/easy money investment to mitigate the erosion problem. After this "political solution" and during the last two years, the national government has invested US $8 million for building a 348 m igneous rock revetment that has so far been unsuccessful (Fig. 6). Unfortunately, this new hard structure has generated coastal retreat of 60 m during the last year in the western part of the sector.

For this failed example of protection with hard structures, a planned retreat option seems an inevitable and probably the most appropriate solution. However, because of the current status of Natural National Park, existing legislation impedes relocation of the road generating a conflict between stakeholders.

3.7.3. Tourism on the rocks: groins and breakwaters along Tolu and Coveñas (Sucre)

Located on the Morrosquillo Gulf, the cities of Tolu and Coveñas are some of the emerging tourist destinations of the Caribbean coast of Colombia. This coastal section has a length of 22 km and consists of small sandy beaches backed by low-lying coastal plains and mangroves. During the last 10 years, the entire coastline between both cities has experienced considerable erosion rate variations, with values reaching 3 m yr^{-1}, mainly related to human-induced sedimentary imbalances (Rangel-Buitrago et al., 2015a,b).

Along the area, groins, breakwaters, and seawalls of calcareous blocks have been built, most without proper coordination and design generating continuous erosion (Fig. 7). Erosion has lead to the breaching of protecting barriers and thereby to increasing salinity in the lagoon, destroying mangroves and hampering local freshwater extraction (Delgadillo and Ruiz, 2016).

Along the Tolu and Coveñas sector, a total of 342 (both cross and longshore) structures were observed. The most common hard protection was groins with 281 individual elements, and a cumulative length of 7,34 km. The groins are made of blocks of calcareous rocks extracted from nearby quarries, at an average cost of 50 US$ m^3 (Fig. 7). Due to the absence of longshore sediment, groins are useless and give rise to significant unattractive impacts.

Thirty-eight breakwaters with a total length of 3.1 km are found in this sector. Breakwaters have been constructed with blocks of calcareous rocks to protect and hopefully enlarge beaches (Fig. 7). By contrast with unsuccessful groin structures, these breakwaters have functioned, in some cases enlarging the backing beach by creating well formed "tombolos" (five in total), with an occurrence of slight downdrift erosion.

Twenty-three sea walls with a total length of 2.5 km have been constructed mainly to protect urban areas from severe storms and floods coinciding with unusually high tide conditions annually recorded in February and March.

The total length of coastal protection is 12.9 km, which is 59% of the total coastline. In detail, seawalls and breakwaters represent 25% and groins 34% this value. Most protection structures were constructed in an attempt to stop erosion processes, responding to

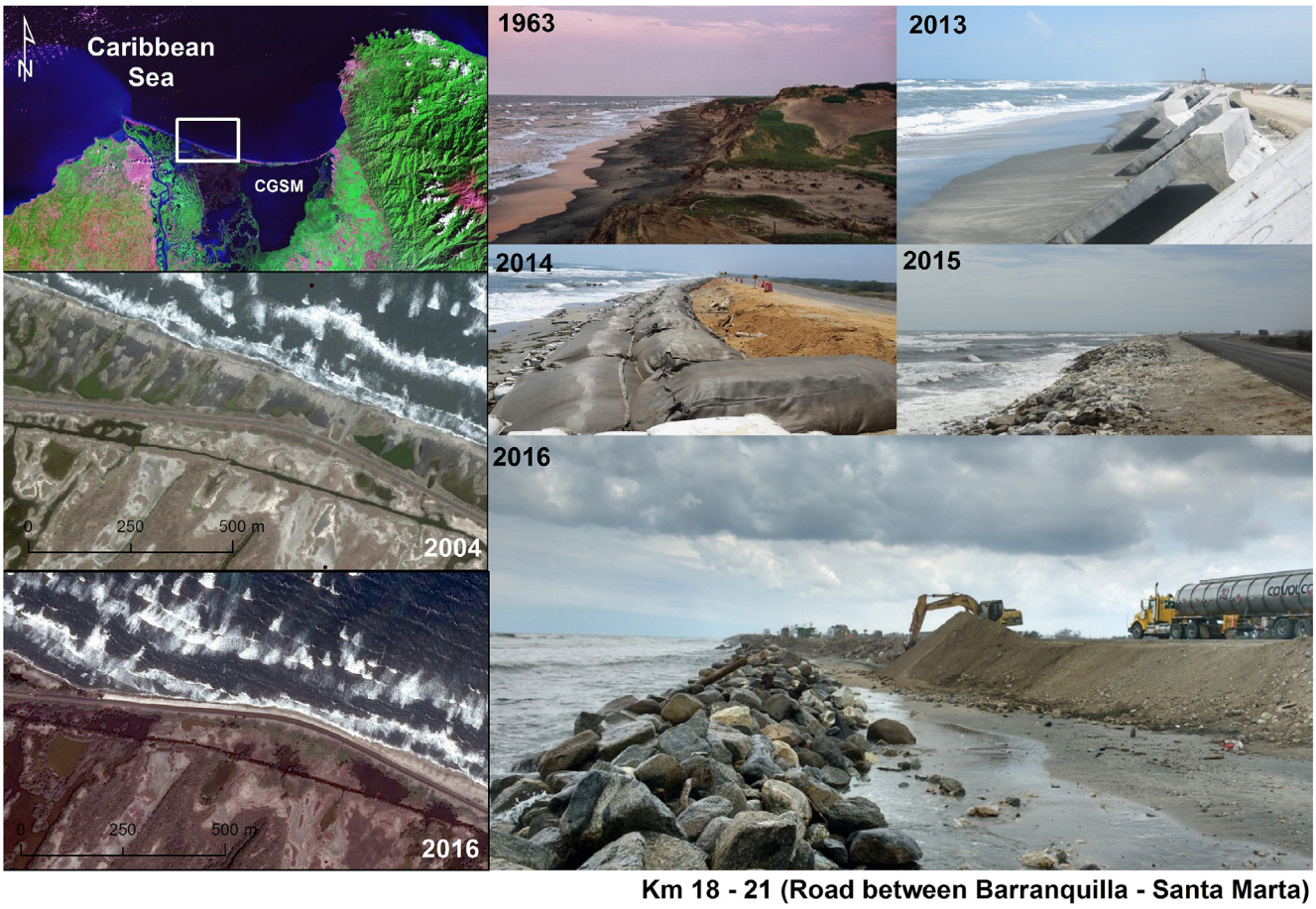

Fig. 6. Km 18–21 study case. images shows the evolution of the area as well the revetment construction evolution during the last 3 years (oblique photos, Satellite and Terraserver images for 2004–2016 period).

the growth of population, which has increased to about 4000 inhabitants in the past five years, and to enhance national and international tourist demand, which increased by about 40% in the last ten years (ANATO, 2016; DANE, 2016).

Until now finances spent on hard structure strategies in this sector has exceeded US$80 million, this can be considered as excessive given the low functionality and inefficiency of constructed structures. Local government is planning to invest at least US$ 12 million more to mitigate erosion using hard structures, beach nourishment, implementation of Reef Balls and mangrove restoration.

3.7.4. Protecting with the forbidden: hard protection structures along the Corales del Rosario y San Bernardo National Natural Park

One of the largest parks in Colombia is the Corales del Rosario y San Bernardo National Natural Park (CRSB) located SW of Cartagena city. The CRSB was created in 1977 to protect 180 km^2 of marine habitats, and was expanded in 1996 to 1200 km^2 encompassing reef ecosystems located around the San Bernardo Islands (Zarza-González, 2011). This park has a variety of coastal and marine ecosystems and harbours important marine and coastal biodiversity.

However, environmental degradation within the park and surrounding areas has occurred for several years, resulting in a decline in seagrasses, mangroves and coral coverage, an increase in coral bleaching and disease, and loss of biodiversity (Zarza-González, 2011; Rangel-Buitrago, 2011; Bejarano et al., 2016). The above is as result of numerous factors including high sediment loading from the Magdalena River, lack of wastewater treatment and accelerated coastal erosion.

Anthropogenic interventions related to an increase in tourism within the park also contribute. In the last ten years, there has been an increase of almost 103% in tourist arrivals increasing from 220,485 arrivals in 2005 to 448,479 arrivals during 2015 (ANATO, 2016). Currently, pressure is being applied for construction holdings on the CRSB in order to erect hotels and bungalows for tourism development (Fig. 8). However, the CRSB area has suffered constant erosion over the past 50 years as a result of constant wave action and progressive increase in sea level (Restrepo et al., 2012). The above has brought with it an acceleration in the construction of hard structures, although these have been forbidden from 1996.

Within the 44 islands that comprise the natural park, a total amount of 193 (both cross and longshore) structures occur. This number is more than the 135 hard structures reported in the same area by Rangel-Buitrago (2011). The main current hard protection are seawalls (105) having a cumulative length of 35.9 km seawalls were constructed mainly to protect individual summer houses from severe storms (Fig. 8). Groins (68) have a cumulative length of 2.5 km and are impermeable, made of blocks of calcareous rocks, corals, tetrapods and concrete bags (Fig. 8). Due to the absence of sediment, seawalls, and most groins are inappropriate and, generate negative impacts (Fig. 8). Twenty breakwaters with a total length of 245 m were observed along the park constructed with blocks of calcareous rocks and corals. The total length of coastal protection is 8.7 km,

Fig. 7. Tolu - Coveñas study case. a) riprap revetment, b) detached breakwater c)Groin and Jetty at river mouth, d) groin field, e) seawall and groynes, f) revetment and g) seawall. (Oblique photos and Satellite image for 2013).

representing 34% of the CRSB coastline.

The percentage of hard coastal protection within the national park has increased despite a prohibition that has been in place since 1996, highlights the absence of coastal management, poor coordination of inter-institutional efforts and incipient interaction with stakeholders.

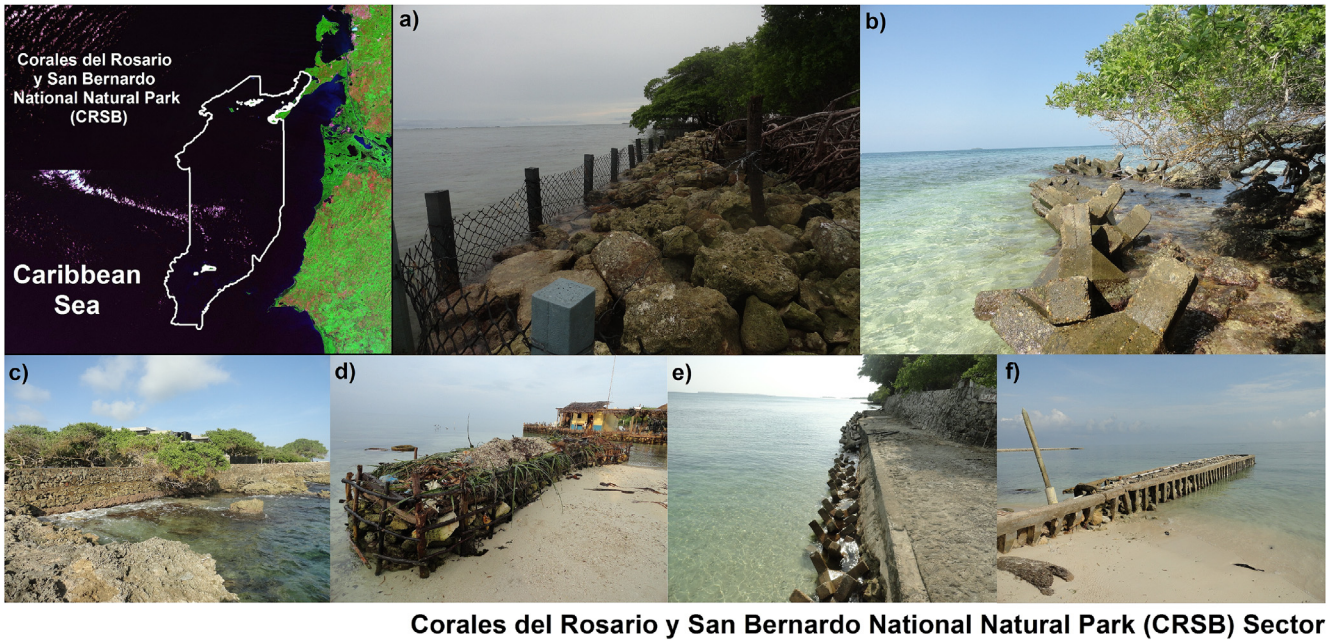

Fig. 8. Corales del Rosario y San bernardo National Natural Park study case. a) rock accumulation as reverment, b) pentapods protecting mangrove, c) seawall, d) litter groin,e) pentaponds for seawall protection, f) fixed groin. (Oblique photos and Satellite image for 2015).

3.8. Effects of coastal hard protection structures along the Caribbean coast

The term "coastal protection" has different meanings (Cooper and McKenna, 2008; Anfuso et al., 2012). To landowners and engineers, "coastal protection" means constructing something to protect property; while to environmentalists, it means letting nature take its course in order to protect the ecosystem. However, coastal protection will be satisfactory only if its impacts are so low as to be disregarded (Anfuso et al., 2012). Unfortunately, coastal protection (especially related to hard structures) usually presents very high impacts in socio-economic, demographic, ecological and physical aspects (Fabbri, 1998; Cooper et al., 2016).

Hard protection structures have been the main management strategy to coastal erosion on the Caribbean coast of Colombia as well as in many Latin American and European countries (Pranzini and Williams, 2013; Silva et al., 2014). A high percentage of the existing hard protection structures have been built and installed as the only response to local stakeholder pressure when properties are exposed to damage and destruction, all without carrying out the minimum required environmental impact assessment, potential risk analysis and collateral effect evaluations. As a result, coastal protection has had adverse environmental impacts (Fig. 9).

In the study area, the most significant impact of hard structures is related to the induced sedimentary imbalance and subsequent erosion generated by the change coastal sediment transport patterns due to primary processes:

- Reflection of incoming waves, hampering energy dissipation with a later increase in turbulence and cross shore erosion, as well as sporadic rip-current generation (e.g. seawalls in the CRSB).
- Diffraction of incoming waves, concentrating wave energy in specific places with subsequent coastal erosion (*i.e.,* breakwaters in Tolu and Coveñas, Sucre);
- Catching sediments transported alongshore, creating a significative sediment deficit downdrift (*i.e.,* groins in Riohacha and Cartagena).

Along the Colombian Caribbean coast there exists the wrong concept that a "hard structure" approach to coastal erosion management must be applied when tourism is the main target. Many hard structures are designed and constructed to fulfill tourist requirements, essentially the need of an increasing beach carrying capacity. However, most do not generate beaches and negatively affects coastal scenery one of the most important parameters for beach users (Williams and Micallef, 2009). Rangel-Buitrago et al. (2013, 2016) and Williams et al. (2016a) observed this at Atlantico, Bolivar, Sucre, and Cordoba departments, where many beaches had few scenic value scores and negative visual impacts due to environmental degradation associated with the construction of hard protection structures (Fig. 9).

Hard protection structures also negatively impact Colombian Caribbean beaches by decreasing water quality and especially favouring litter retention (Fig. 9). Litter caught by hard protection structures in at least 100 beaches within the study area inevitably placed these beaches in a a low scenic category (Rangel-Buitrago et al., 2016; Williams et al., 2016a). The above requires a scenic grade improvement by using extreme litter clean-ups, and in some cases removal of hard protection structures. Likewise, a high percentage of beaches show signs of artificiality *i.e.* much altered by human activity, such as, Cartagena, CRSB, Tolu, and Coveñas. Along these coast cities, urbanization processes have focused on hard structures accompanied by the construction of ports, marinas, promenades and piers, which have increased the coastal armouring process (Rangel-Buitrago, 2009; Rangel-Buitrago and Anfuso, 2011; Stancheva et al., 2011).

When any hard structure is constructed, an area of the beach will be covered by the structure and as a direct consequence an area of the beach will be lost. The extent will depend on of how far seaward and alongshore the structure extends. As with coastal scenery impacts, this is a contentious issue with the public who lose beach area to benefit private property owners (Griggs, 2010). Where a small seawall or revetment is built, there is usually slight space loss because the structure has a limited cross-shore width, perhaps only several meters. However, some large calcareous seawalls and revetments, such as Km18-21 and CRSB examples, have a significant width and cover large beach areas.

In many cases, beach access is lost when a hard structure is installed. The capacity to get to a beach from behind or above (vertical access) is affected when seawalls, revetments, and rip-raps are placed on the coast (Fig. 9). The above is the case for revetments built at the Km 18–21, and Cartagena that hinder direct beach access. On the other hand, lateral access is restricted when structures, usually groins, bisect the shore-parallel continuity of a beach (e.g. Tolu and Coveñas). In some countries stairways and elevated walkways mitigate the reduction of beach access, but this is not the case in the study area. The previously mentioned effects related to construction of hard protection structures are a typical sequence of events where one wrong action is "countered" by a subsequent one, which in turn creates other problems (Cooper and McKenna, 2008; Cooper et al., 2009; Pranzini and Williams, 2013).

The coastal Caribbean hard protection management strategy also highlights an additional common problem in the degradation caused by efforts to preserve the interests of a small number of stakeholders. In Colombia, this not only is affected by society in general through loss of environmental quality and amenity, but is paid for through public funding of such structures (Cooper and McKenna, 2008; Rangel-Buitrago et al., 2015a,b).

Along the study area, coastal erosion management has been essentially focused on the hard protection approach at any cost. These actions evidence a gap of information and distancing among different authorities involved in coastal management emphasizing the necessity for future research to examine the impact of defense measures on the environment (Semeoshenkova and Newton, 2015; Manno et al., 2016).

3.9. Considerations for coastal erosion management

According to Colombian population data, nine percent of Colombian inhabitants are located along the Caribbean coastline (DANE, 2016), so ample scope exists to develop optimal coastal erosion management for beach use purposes, as well as for the well being of the local population. Coastal erosion and bad management practices affect tourism which has a broad range of connections to other productive sectors, such as, transport, restaurants, etc. and indirectly affects national incomes and job generation. In essence, coastal erosion management strategy is an issue strongly linked to the competitiveness of the country.

Adequate coastal management and conservation requires that the present use of coastal resources must meet the needs of the population without endangering the ability of future generations to respond to their needs. Coastal erosion management strategies require implementation of effective and efficient solutions based on knowledge of magnitudes, trends and causes (Komar and McDougal, 1988). It must also include beach users' priorities and preferences identifying, maintaining and, where possible, enhancing the value of beaches to the economic, environmental and social well-being of local communities.

The Colombian hard protection strategy was virtually always

Fig. 9. Examples of hard structures related impacts. a) tires block access and generate damages in ecosystems, b) generation of rip currents that affect swimmers (danger: avoid swimming close structures), c) coastal squeeze, d) litter accumulation, e) eutrophication process, f) danger to swimmers. (Oblique photos).

carried out regardless of the existence of other protection options (such as, beach nourishment or other soft solutions), ignoring the possibility of implementing other coastal erosion management strategies, such as "Accommodate," "planned retreat," or "do nothing" (Williams et al., 2017).

Given the appropriateness of hard protection structures, it is clear that along the Colombian Caribbean coastline, the current coastal erosion management strategy is too weak and requires change. The short-term perspective conditioned by economic considerations manifested in an action-reaction basis (Rangel-Buitrago et al., 2015a,b) or a cost-benefit analysis approach (Cooper and McKenna, 2007) is not working, making it clear that Colombian coastal management must be focused on identifying coastal problems together with mitigation strategies from a regional and long-term perspective.

Worldwide coastal erosion studies increasingly recognize the environmental damage caused by hard stabilization structures (Zhu, 2010; Griggs, 2010; Cooper and Pilkey, 2012; Nordsrom, 2014; Rangel-Buitrago et al., 2015a,b). The above is a difficult problem to work with because there are still those who deny their impacts, e. g Basco (2004).

The impact of hard structures remains controversial: there exists an influential lobby who argue that preservation of buildings are more important than the preservation of beaches (Cooper and Pilkey, 2012) and in the Colombian Caribbean case, these people are the beach front property owners and politicians.

Currently, planned retreat options seem an inevitable solution in fast eroding areas and probably the most appropriate solution for human settlements, such as, Tierrabomba, and erosive hot spots along major coastal roads, such as, Km 18–21 (between Barranquilla and Santa Marta). Accommodation consists of land use changes or adaptation of human structures to erosion/flooding processes. In the latter case, houses can be placed along rural coastal areas sporadically affected by inundation processes, such as, some sectors of Cartagena and the CRSB park. Do nothing could be a solution for areas of low economic value that are threatened by erosive processes, such as, beachfront properties, and/or small rural houses found in La Guajira and Cordoba departments. Likewise, the prevention strategy is of great importance if regulations for future coastal developments are implemented, e.g. it would be necessary for restricting certain activities in specific eroding zones which will probably experience severe erosion - this is the case of areas close to tourist cities, such as, Cartagena and Tolu and Coveñas (Sucre).

Coastal erosion management is a complex process that requires a holistic view to finding practical solutions that, many times, go beyond a national issue (Bush et al., 1996; Williams and Micallef, 2009; Cooper and Pilkey, 2012). Coastal erosion management becomes imperative in Colombia because every day that passes the problem becomes more complex and solving the problem by investment of large amounts of money in hard protection structures

is not the answer.

As the Colombian Caribbean coastal population increases and coastal erosion becomes severer, more pressure is applied to government at all levels to try resolve this problem. Unfortunately, from a governance view point, coastal erosion management fails due to a weak institutional framework accompanied by diluted and compromised coastal erosion management regulations.

In Colombia, three governmental Institutions have competencies in this issue: The Ministry of Environment and Sustainable Development (MADS – acronym in Spanish), General Maritime Directorate (DIMAR) and the Colombian Oceanic Commission (CCO). However, it is not clear which Institution is directly responsible for addressing coastal erosion and especially their management; similarly for the particular interferences and functions associated with these important issues. Advances and achievements of these Institutions are too weak and considering the high magnitude of erosion process and their pitfalls when carrying out their management along the Caribbean of Colombia coastline; its results are unclear.

With reference to hard protection structures, in 1993 Colombia promulgated Law 99–1993 which regulates the expedition of an environmental authorization for their construction. For each coastal erosion protection or control measure, Law 99-1993 orders the mandatory development of an environmental impact assessment to obtain authorization. The building of any hard structure must be approved and verified before construction by the National Authority of Environmental Licenses (ANLA). This approval depends on the compliance with an extensive protocol denominated Td-07 which is regulated by the ANLA resolution nº 1660. The Td-07 covers at least twelve different aspects that include amongst others detailed study of hydrodynamic, biotic and social conditions of the area where the hard structure will be constructed as well as their technical specifications and costs. This legal action is consistent with the fact that any hard structure will affect a beach, its scenery and, as a consequence, incomes linked to the environmental and tourist sectors. Unfortunately, this mandatory planning instrument is taken into account only in coastal areas where environmental authorities can exercise any control. Along the Caribbean coast of Colombia exist many remote locations (*i.e*. Antioquia, Cordoba and La Guajira) where, because of the absence of environmental authority, different types of hard structures are constructed without any previous environmental impact assessment.

In some cases, environmental authorization delays due to excessive bureaucracy gives time for stakeholders to build illegal hard structures that invariably exacerbates erosion. In others cases during hard structure construction the ANLA stops the process when it considers it necessary, generating serious problems in the original design and final result.

Currently, coastal erosion is occurring on a national scale leaving a big question **How can Colombian policies and directives help to manage the coastal erosion issue?** At this point in Colombian history, it is rather disappointing that there is a lack of optimal legal requirements concerning coastal erosion management.

However, the main achievement has been the creation of the National Programme for Research, Prevention, Mitigation and Control of Coastal Erosion in Colombia (Guzman et al., 2008), established for the 2009–2019 period and headed by MADS. However, this is just a document, and implementation has yet to begin. Within the institutional framework, coastal erosion and management has been a frequent issue, but at the end of the day, no one has legal responsibility for any implementation.

A country, such as Colombia, especially its Caribbean coast, might take into account successful coastal erosion management strategies applied in different part of the world. For example, the Erosion Project by the European Union developed in 2004 formulated four elements as a basis to define a policy to combat coastal erosion:

- Enlarge coastal resilience by restoring the sediment balance and providing space for coastal processes.
- Incorporate coastal erosion costs and risks in existing planning and policy instruments.
- Make responses to coastal erosion accountable.
- Reinforce the knowledge base of coastal erosion management and planning.

Coastal erosion management along the study area (as well as other places around the world) should be based on strategies that allow an inherent ability of the coast to accommodate change induced by erosion whilst maintaining the functions fulfilled by the coastal system over medium and long terms. A short term vision underpinned on hard protection structures does not allow the above mentioned to occur. For this to happen, it is necessary to consider the different coast types and their related processes involved in order to define the strategy to be implemented (Williams and Micallef, 2009; Pranzini and Williams, 2013; Pranzini et al., 2015).

Flexible strategies, *i.e.* proactive and not reactive measures, should be adopted to strengthen coastal erosion management. For example, extreme wave events, such as, hurricanes seldom occur, but erosion management plans must be updated and in force to deal with these occurrences. For these kind of events, it might be necessary to incorporate beach and river basin management.

Coastal erosion monitoring must be used as a tool for beach management purposes and may lead to establishment of local and national legislation for better coastal erosion management along the coastlines of Colombia. Monitoring practices stimulate the sense of environmental responsibility and encourage public participation in the activities related to the maintenance of coastal environmental quality (Liu et al., 2013). It is important to know that raising public awareness of the influence of hard structures over beach quality is a guaranteed way of reducing their impacts.

In general terms, coastal management authorities need a robust and clear management framework to resolve issues related to coastal erosion. These need to be focused on specific points:

- Comprehension of the underlying processes involved in sediment transport to choose the best coastal erosion management strategy.
- Facilitate community involvement on coastal erosion and their management issues.
- Evaluate and determine the optimal strategy for coastal erosion control and management taking into account viewpoints of all stakeholders and above all the technical concepts.
- Lay aside the concept “good, beautiful and cheap” widely applied for coastal erosion management.

Government institutions can achieve such objectives by undertaking a law reform agenda based on five fundamentals points:

- Update current Colombian environmental legislation with strong management rules focused in coastal erosion, which also must be implemented.
- Add new measures to better support decision-making, including a decision support framework including a coastal erosion manual.
- Reducing individual consequences over the environment related with hard structures construction.
- Raising public awareness about risks associated with illegal construction of hard structures.

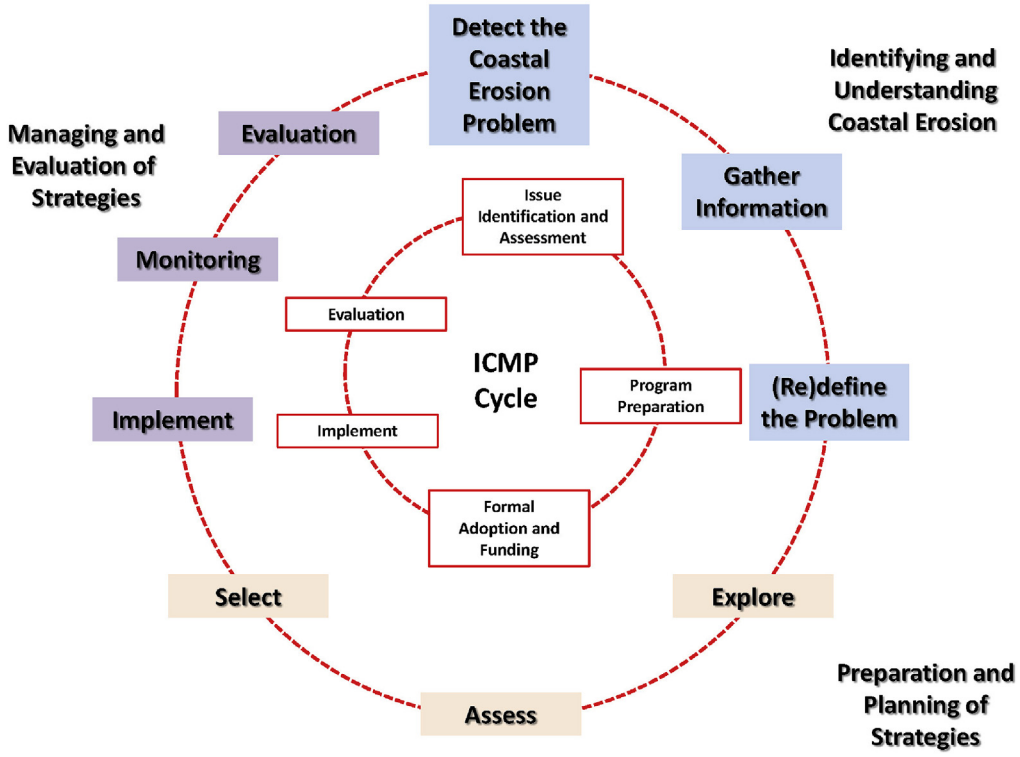

Fig. 10. Steps to follow in the coastal erosion management scheme taking into account the integrated coastal management policy cycle (adapted from Olsen et al., 1997).

- Providing an efficient and sustained response to coastal erosion issues.

Under current climate change conditions, a coastal erosion management plan is required. Fig. 10 illustrates the steps to follow in the scheme taking into account aspects under the integrated coastal management policy cycle formulated by Olsen et al. (1997). The above must be included in politics, supporting strategies and must be built with enough scientific research for decision makers to make rational decisions This proposed plan can achieve continual improvement of coastal erosion management throughout the entire Country.

4. Conclusions

Coastal erosion has become a serious problem rising in magnitude along Colombian Caribbean coastline. *Circa* 50% of this critical area is undergoing serious erosion related to a multiplicity of factors contrasting by their degree of influence and magnitude.

The 2445 km long Caribbean coastline has a recent history of human occupation and interventions in managing coastal erosion process. In addition to this, coastal development that began in the last 50 years has accelerated during the past two decades with increased human mobility and affluence.

Hard structures have been the first management strategy for coastal erosion problems. At the beginning of 2016, 1484 hard structures existed along the coast, the highest concentrations being located in tourist cities. A significant percentage (close to 90%) of the total amount of these hard structures has not been very successful or failed in their purpose.

The disadvantages of the use of hard structure include: irreversible coastline modifications; loss or damage of the natural landforms, aggravation of erosion downdrift, adverse visual impacts, potential risks for people's life and lost access for swimmers to the water area.

With continuously growing coastal settlements, there is no doubt more protection measures will be required. The current approach, whereby protection is commonly provided at public expense, suggests that Colombian communities have not “learnt” from past bad management practices.

It is important that a new coastal management strategy be introduced that takes into account current conditions of principal human occupation and coastal erosion processes. Since traditional hard defense methods used so far have had more damaging than protective effects, there is a need now for the use of soft prevention alternatives and for providing new guidelines for coastal management.

Along the study area negative impacts from the implementation of hard structures as protection measures against coastal erosion dominate. Direct and indirect experience indicates that optimal results, on money and a time basis, can be achieved using a combination of other protection options, such as, “accommodation,” “planned retreat,” or “do nothing” solutions delivered through legally adopted coastal management plans, co-ordinated by one government department is urgently required. Unfortunately, hard protection measures still remain a priority consideration. The examples listed in this paper and much more existing in this country prove that current coastal infrastructures have been more of a pitfall than a solution.

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